NAVAL MEDICAL RESEARCH INSTITUTE

Bethesda, MD 20889-5055

NMRI 91-15 April 1991

PRELIMINARY DIET AND HYDRATION GUIDELINES FOR DIVING TO DEPTHS TO 150 FSW

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TECHNICAL REVIEW AND APPROVAL

NMRI 91-15

The experiments reported herein were conducted according to the principles set forth in the current edition of the "Guide for the Care and Use of Laboratory Animals," Institute of Laboratory Animal Resources, National Research Council.

This technical report has been reviewed by the NMRI scientific and public affairs staff and is approved for publication. It is releasable to the National Technical Information Service where it will be available to the general public, including foreign nations.

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION: UNCL

1b. RESTRICTIVE MARKINGS:

2a. SECURITY CLASSIFICATION AUTHORITY:

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE:

3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution is unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S): NMRI 91-15

5. MONITORING ORGANIZATION REPORT NUMBER(S):

6a. NAME OF PERFORMING ORGANIZATION: Naval Medical Research Institute

6b. OFFICE SYMBOL (If applicable):

7a. NAME OF MONITORING ORGANIZATION: Naval Medical Command

6c. ADDRESS (City, State, and ZIP Code): 8901 Wisconsin Avenue, Bethesda, MD 20814-5055

7b. ADDRESS (City, State, and ZIP Code): Department of the Navy, Washington, DC 20372-5120

8a. NAME OF FUNDING / SPONSORING ORGANIZATION: Naval Medical Research & Development Command

8b. OFFICE SYMBOL (If applicable):

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER:

8c. ADDRESS (City, State, and ZIP Code): 8901 Wisconsin Avenue, Bethesda, MD 20814-5044

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
63713N	M0099	.01A	1003

11. TITLE (Include Security Classification): (U) PRELIMINARY DIET AND HYDRATION GUIDELINES FOR DIVING TO DEPTHS TO 150 FSW

12. PERSONAL AUTHOR(S): T.J. Doubt, J.W. Thorp, and P.A. Deuster

13a. TYPE OF REPORT: Technical Report

13b. TIME COVERED: FROM 1986 TO 1990

14. DATE OF REPORT (Year, Month, Day): 1991April

15. PAGE COUNT: 35

16. SUPPLEMENTARY NOTATION:

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): fluid balance, nutrition, energy balance, exercise, hyperbaric exposure, immersion diuresis

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This report provides a brief review of dietary and hydration changes associated with immersion and hyperbaric exposures to a depth of 150 feet seawater (fsw), and recommendations for ensuring adequate fluid and caloric status. Significant loss of body fluid will occur with immersion. Fluid replacement during immersion does not totally reverse this finding. Adequate predive hydration is required, especially in hot environments, and can be judged adequate if the urine is pale in color. For exposures lasting longer than 3 h it is recommended that 500 ml of fluid be ingested per hour. Although this will not reverse the effects of immersion diuresis, it may help prevent significant dehydration and the potential for cardiovascular collapse upon exiting the water. Predive diets should provide 40-50 kcal/kg/day (3200-4000 kcal per day). A minimum of 50% of the calories should be derived from carbohydrate, and fat intake limited to about 30% of the calories. Similar diets should be used during saturation dives and postdive periods. Repetitive dives occurring with less than a

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION: Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL: Regina E. Hunt, Command Editor

22b. TELEPHONE (Include Area Code): (202) 295-0198

22c. OFFICE SYMBOL: SD/RSD/NMRI

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

24-hour surface interval require 600 grams of carbohydrate per day to replenish body glycogen stores. Caloric supplementation during immersion may be required for dives lasting >3 h. This can be achieved by ingesting 250-500 ml per hour of a solution containing 17-34 gm carbohydrate (7% glucose polymer solution). The osmolality of beverages consumed should be less than 260 mOsm to minimize occurrence of gastrointestinal disturbances.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS

This work was supported by the Naval Medical Research and Development Command Work Unit No. 63713N M0099.01A-1003. The opinions and assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Navy Department or the naval service at large.

A. INTRODUCTION

The purpose of this report is twofold. The first is to provide a brief review of dietary and hydration changes that were measured during research studies conducted at the surface and to depths of 150 fsw. This information, from both dry and immersed studies, describes the types of changes that can be expected to occur in operational types of diving.

The second purpose of this report is to provide guidelines for diet and hydration that can be used for planning and conducting operational dives. A series of tables outline the recommended procedures. The scope and limitations of these guidelines are discussed in the text.

B. BACKGROUND

This section provides background information on hydration and dietary studies relevant to immersion and hyperbaric exposures. The data presented were obtained from human studies.

1. Changes in hydration status

In dry conditions, urine flow is about 1-2 ml/min in a normally hydrated person. Flow rates of 5-9 ml/min have been reported in resting subjects consuming 250-1000 ml of water per hour in 25-38 °C air (6,16).

Immersion results in a diuresis that increases urine production and the rate at which fluid is lost from the body. Urine flow rates increase within 30-60 min after the onset of immersion to values of 3-10 ml/min. In the absence of fluid intake these high

urine flow rates will diminish as the diver becomes dehydrated. Average values for 3 h of immersion in 25 and 35 °C water while at rest were 5-6 ml/min (6), and 3 h of intermittent exercise in 34.4 °C water resulted in an average flow of 6 ml/min (16). The latter value may be slightly higher than expected since the divers were drinking one liter of water per hour during a 4-hour predive period. For immersions lasting 3-6 h, a diver can typically lose 1-4 liters of body fluid through the urine (7,12,16), which is equivalent to a reduction in body weight of approximately 1-4 kg (2-8 lbs). Open-water training dives in 58 °F water lasting 7.5-13 h resulted in an average weight loss of 7.3 pounds (3.3 kg) (personal communication).

Divers at 20 fsw in 5 °C water (41 °F) for 6 h, wearing a dry suit, produced 1.6 ± 0.2 liters of urine during AM immersions (1000-1600 h), and 0.8 ± 0.1 liters during PM (2200-0400 h) exposures (7). The lower urine production during nighttime dives was the result of circadian influences on urine flow. This magnitude of fluid loss resulted in a 17% reduction in plasma volume (the fluid portion of blood) for both AM and PM dives. The decrease in plasma volume, in turn, required an equivalent increase in exercise heart rate in order to perform work (10). Equivalent loss of fluid and decrements in performance were also observed during a 7-hour sequential 5 °C wet-dry-wet exposure in divers wearing passive thermal protection (12).

Attempts have been made to minimize the dehydration resulting from immersion by providing fluid to drink. Ingesting 250 ml of either water or a commercially available glucose polymer solution (Exceed, Ross Products) each hour during 3 h of resting immersion in 35 and 25 °C water did not improve hydration status

(compared to not drinking fluid). Fluid ingestion simply increased the volume of urine produced during immersion. Plasma volume remained the same as in the no-fluid condition (6). Similar findings were reported when divers drank a solution containing glycerol, which theoretically should have retained more fluid in the vascular compartment by an osmotic effect (1). Preliminary research has found that intranasal administration of an analog of arginine vasopressin (desmopressin acetate) reduced immersion diuresis 80-90% in resting males in thermoneutral water (Lockette, personal communication). Additional studies are required to determine the efficacy of this drug during operational dives.

Drinking 250 ml of a glucose polymer solution each hour during intermittent rest-work cycles in 25 ° C water also did not improve hydration status (9). Urine production during the 2-hour immersions was higher by an amount equal to the volume of fluid ingested (596 ± 141 ml urine for no fluid vs 1065 ± 129 ml when drinking fluid). The same results were obtained when the divers were at 150 fsw (5.5 ATA) breathing a helium-oxygen mixture. This finding indicates that immersion diuresis was unaltered by depths to 150 fsw.

Hot humid environments can lead to marked dehydration in the predive period if adequate amounts of fluid are not consumed. Performance during and after dives conducted in this environment can be impaired. Standby divers are also at risk for dehydration and heat stress injury under these conditions. Therefore, the issue of adequate predive hydration is of more than academic concern. A recent study had divers drink 1 liter of water per hour during a 4-hour predive exposure in 37.8 ° C air (16).

Subsequently, a 3-hour dive to 20 fsw was performed in 34.4 ° C water. At the end of the dive the average reduction in body weight was only 1.3 kg. This was less than the 2.1 kg lost after a 7-hour wet-dry-wet exposure, where only 400 ml of water was consumed (12).

While fluid ingestion appears to have little effect on hydration status over the course of long dives, there are theoretical reasons why it might transiently lessen the decline in plasma volume. Any fluid ingested will eventually be absorbed from the gastrointestinal tract into the vascular compartment. Although this fluid will ultimately increase urine production, it will temporarily increase plasma volume. If the fluid is ingested shortly before attempting exercise or exiting the water, then the brief rise in plasma volume might lessen the physiological stress of work (when compared to not drinking fluid). This is illustrated conceptually in Figure 1. The line AB represents the decline in plasma volume during immersion if no fluid was consumed. The magnitude of the loss in plasma is represented by AE. If fluid were ingested (at arrow in figure), a transient increase in plasma volume would occur. A subsequent decline would follow returning to the no-fluid condition; the theoretical time course is shown by ACB. Notice that the height of CD represents the benefit of fluid ingestion above that of the no-fluid condition. It can be theorized that point D represents an optimal time to start work or to exit the water, since the higher plasma volume would be associated with a lower exercise heart rate or reduced incidence of post-immersion syncope. Thus, the timing of fluid ingestion during a dive can be an important aspect of mission planning.

In summary, immersion will markedly increase the amount of body fluid lost through the urine. Physical performance will decline as a consequence of the loss in plasma volume. Ingesting fluid during immersion will not completely offset these losses in body fluid. Similar findings also occur at depths to 150 fsw, with no change due to depth per se. However, the timing of fluid intake may be of some advantage prior to a work period, or lessen the effects of dehydration (e.g., orthostatic intolerance) when getting out of the water. Adequate predive hydration will minimize effects due to in-water fluid loss.

2. Dietary and energy expenditure changes

A diet survey, obtained in free-living divers, indicated that their dietary patterns were adequate when compared to current guidelines for healthy living in the general population (15). Caloric intake averaged 2800 kcal per day. However, only 40% of the calories were obtained from carbohydrate sources. It is usually recommended that at least 50% of total calories should come from carbohydrate for individuals involved in strenuous physical activity (3,4); 400-600 grams of carbohydrate per day are required. In the absence of adequate carbohydrate intake, replenishment of muscle glycogen is slowed, glycogen levels decrease, and performance declines (5).

High carbohydrate diets are commonly consumed by athletes to increase muscle glycogen stores prior to competing in endurance events (4). We have shown that a 3-day high carbohydrate diet (600 gm per day) will increase the amount of work that can be done during strenuous exercise in 25 °C water when compared to a 3-day normal diet (300 gm/day) (18). It can be concluded from this study that carbohydrate loading

will likely benefit a diver who has to perform strenuous work for long periods of time. Dietary plans for carbohydrate loading are readily available (11).

Studies conducted before the start of saturation dives revealed a daily energy expenditure of 3200-3500 kcal per day measured during a 24-hour period in a metabolic chamber. Daily energy expenditure was 8% higher at 150 fsw than at the surface (13). The divers consumed 50 kcal/kg/day at depth and were able to perform a variety of tasks during the 12 days at 150 fsw. Protein synthesis and turnover rates were reduced approximated 50% at depth (2). Meal plans that provide 3600 kcal per day are available as a NAVMEDRSCHINSTITUTE Technical Report (17).

Compared to dry conditions, the energy required to perform work in water is greater because of resistance. Wearing thermal protection garments or an underwater breathing apparatus will increase the energy cost of exercise by an additional 10-30%. In addition, the thermogenic response to cold water will increase the rate of energy expenditure. For example, exercise in 18 ° C water required about 3 kJ/min greater energy expenditure than when the same workload was done in 28 ° C water (8). The energy cost of performing work in warmer water (compared to cold water) will depend on exercise intensity and water temperature. If excess metabolic heat can be dissipated, core temperature will not rise, and oxygen consumption will be equivalent to cooler conditions.

The amount of energy expended during a dive will depend on the work rate. Furthermore, the amount of energy derived from carbohydrate or fat sources will change during the dive because of a progressive shift from carbohydrate utilization to greater

reliance on fatty acid oxidation. This concept is modelled in Figure 2 at four levels of work (measured by oxygen consumption) during a 6-hour theoretical dive. At each workload the amount of energy from carbohydrate sources, shown over each 30-minute segment, decreases and that from fat increases. At workloads greater than 60% of maximum aerobic capacity ($\dot{V}_{O_2}$ of 2.0 L/min in graph) the ability to provide adequate amounts of glucose can become the limiting factor to endurance.

Figure 3 illustrates the amount of carbohydrate utilized during the work periods shown in Figure 2. Summing the points on each curve yields the total amount of carbohydrate used. Note that at the highest workload ($\dot{V}_{O_2}$ = 2.0 L/min) the total amount of carbohydrate used after 2 h (~180 grams) would substantially deplete body glycogen stores (about 75-90 gm in the liver, and 1 gm glycogen per 100 gm of muscle). If this were to occur, blood glucose would be the primary source of carbohydrate. The high work rate, however, would use blood glucose at a rate faster than could be generated; blood glucose levels would decline, and exhaustion would soon occur (4). Providing a source of exogenous carbohydrate delays the onset of fatigue or exhaustion during long periods of exercise, in part, by preventing this decline in blood glucose. Replacing 15-30 grams of carbohydrate per hour during strenuous work can be sufficient to promote endurance. Such replacement, using glucose polymer solutions (250 ml of 7% solution provides 17 gm), can be conveniently achieved during a dive if a drinking tube is installed in the diving facemask or helmet.

C. HYDRATION GUIDELINES: NON-SATURATION DIVES

Appendix A presents a table of the recommended patterns of fluid intake for predive, during immersion, and postdive conditions.

1. Predive hydration

Adequate amounts of non-alcoholic fluid should be consumed for 24 h prior to the start of a dive. In general, fluid intake can be judged as adequate if urine is produced that is pale in color and clear. Low fluid intake is associated with infrequent urination and a urine that is dark and opaque. The volume of fluid necessary to ensure adequate hydration will depend, in part, on environmental temperature. In hot climates loss of body fluid may be about 8-12 liters per day because of increased sweating. Cold climates may also increase the rate of fluid loss secondary to cold-induced diuresis. Further, the logistics of conducting an operational dive may result in a reduced fluid intake because personnel are preoccupied with other tasks. Regardless of the environmental conditions, fluid should be consumed on a regular basis since the body's thirst mechanism is an unreliable indicator of body fluid requirements.

Five ml of fluid per kg of body weight (about 400 ml, or 12 fl. oz. in an 80 kg diver) should be consumed within 1 h before diving. Standby divers should drink 250-500 ml/h, the amount depending on environmental temperature and the type of thermal protection garments worn.

Drinking excessive amounts of fluid (more than about 1 ℓ/h) is of no prospective benefit, and may even be deleterious. Excess fluid intake will be excreted by healthy individuals, and high rates of urine flow may increase loss of sodium. The

syndrome of "water intoxication" occurs with ingestion of large amounts of water and is associated with mental confusion and decrements in physical performance.

2. Fluid replacement during immersion

If the duration of a dive is less than 3 h there is probably no advantage to drinking fluid, provided the diver is well hydrated at the start of the dive. There may be some advantage to ingesting fluid for dives lasting longer than 3 h. If no fluid is consumed during these long dives, it is known that dehydration and hypovolemia (low blood fluid level) will develop. While a diver is immersed, the hydrostatic pressure will support the blood pressure in the presence of hypovolemia. However, after exiting the water the loss of hydrostatic pressure can result in a redistribution of the available blood volume, and symptoms of hypovolemia (low blood pressure, fainting) might occur. Such an event can occur after either warm or cold water diving. Drinking 500 ml/h (~16 oz/h) will increase the rate of urine production, but it will lessen the chance that the diver will collapse when he exits the water. Drinking 250-500 ml of fluid within 30 min of surfacing can lessen the magnitude of postdive hypovolemia.

For long duration dives (>3 h) the ingested fluid should contain carbohydrate, preferably in the form of glucose polymer. While not better than water alone for maintaining hydration, glucose polymer solutions do provide carbohydrate to help support blood glucose levels, especially during exercise. Many sources of carbohydrate beverages are available (19), and several are listed in Appendix C. The selected source should provide a solution that is slightly hypo-osmotic (e.g., <260 mOsm), because these solutions are absorbed from the gastrointestinal tract about

as fast as plain water. Hyperosmotic solutions are absorbed slowly and are associated with a high incidence of gastrointestinal distress, including nausea and vomiting. Notice that most of the beverages listed in Appendix C are hyperosmotic and should be diluted with the amount of water shown to obtain osmolality <260 mOsm. Any beverage should be taste-tested before the day of the dive to ensure the individual will be able to tolerate the solution in the recommended amount.

While fluid ingestion during immersion will increase the rate of urine production, this should not interfere with normal dive operations. Overboard urine dump systems are currently available for dry suits that permit urination whenever required.

3. Postdive rehydration

A simple, yet effective, way to determine how much fluid a diver has lost during a dive is to measure body weight before and after the dive. The difference between predive and postdive weight will be largely due to fluid loss. Since 1 kg of weight loss roughly corresponds to 1 liter of fluid (16 fl oz per lb of weight loss), the amount of fluid necessary for adequate rehydration is equivalent to the weight loss. If body weights cannot be obtained, the diver should drink 1 liter of fluid per hour until the urine is clear or pale in color. Alcohol or caffeinated beverages are not appropriate as replacement fluids since they increase urine production. Rehydration can usually be accomplished within 2-3 h after surfacing, but more time may be required after exceptionally long dives. These recommendations should be followed, rather than relying on a diver's sense of thirst; the latter often results in voluntary dehydration.

D. HYDRATION GUIDELINES: SATURATION DIVES TO 150 FSW

Appendix B provides hydration recommendations for saturation diving. There is some evidence that water turnover rates are increased at depth. Therefore, adequate amounts of fluid should be readily available throughout the day. Supervisory personnel should monitor the divers' fluid intake to ensure that 3-6 liters of fluid are consumed per day. Relying on a diver's sense of thirst may underestimate his fluid requirement. There is no evidence that drinking excessive amounts of fluid will lessen the risk of decompression sickness.

E. DIETARY GUIDELINES: NON-SATURATION DIVES

Appendix D presents the dietary guidelines. The types and amounts of food appropriate for adequate predive and postdive nutrition can be found in separate Technical reports (11,17).

1. Predive

The caloric intake should average 40 kcal/kg/day (3200 kcal for a 175 lb diver) when engaged in daily light-moderate work or exercise. When heavy work or exercise (90 min continuous per day) is done the intake should be increased to 50 kcal/kg/day (4000 kcal/day for a 175 lb diver). At least 50% of the calories should come from carbohydrate (400-600 grams per day). Appendix G provides a list of foods that are high in carbohydrate. Caloric intake from fat should be limited to about 30% of the total calories (105-135 grams per day). Excess fat (more than 30% of the calories) should be avoided. Not only is it generally unhealthy to exceed this amount, but

digestion becomes more difficult in stressful situations. Protein intake should average 1.0 gram/kg/day.

It is often easier to consume these diets by eating 3-5 meals per day at regular intervals. This spacing improves digestion and nutrient utilization. Large meals should not be eaten within 4 h of starting a dive since digestion may be impaired or the diver may experience gastrointestinal discomfort during the dive.

Modest sized meals may be eaten 1-4 h before a dive, providing 1-5 grams carbohydrate per kg body weight (0.5-2.3 grams per lb) (14). The fat content of the predive meals should be kept as low as possible. Appendix F provides sample predive meals high in carbohydrate. Note that the amount of carbohydrate, and the size of the meal, is smaller the less time between the meal and the start of the dive. For example, 1 gram carbohydrate per kg is eaten 1-2 h before a dive and 5 gm per kg can be eaten 3-4 h before a dive.

There is no evidence that vitamin, mineral, or amino acid supplements enhance performance. Adequate nutritional practices provide all of these essential nutrients. Supplements will not compensate for meals that are skipped or otherwise nutritionally inadequate.

2. <u>During immersion</u>

For dives lasting less than 3 h, there is little practical benefit to ingest caloric solutions during the dive. Adequate predive intake will suffice to meet the energy needs for most short-duration dives. Periodic drinking of beverages during the dive will not be

harmful, and may ameliorate the dryness in the mouth associated with breathing dry or warm gases.

If the dive will be longer than 3 h, exogenous calories from carbohydrate sources may be useful. Refer to Appendix C for the types and amounts of beverages. For light activity a reasonable goal would be to ingest about 17 gm of carbohydrate per hour in solution (e.g., 250 ml of 7% glucose polymer solution). For hard work it is reasonable to increase carbohydrate solution intake to about 34 gm/h (e.g., 500 ml of 7% glucose polymer solution). Never attempt to increase the amount of carbohydrate in any beverage by adding extra glucose powder to the recommended amount of water. In other words, mix according to directions on the package and in Appendix C. Hyperosmotic solutions delay absorption, and may lead to marked gastrointestinal distress. Notice also in Appendix C that hyperosmotic solutions must be diluted with additional water, increasing the volume necessary to achieve the desired carbohydrate intake. For this reason glucose polymer beverages (e.g., Exceed) may be more practical.

The volume of any carbohydrate beverage will contribute to the amount of fluid recommended under the hydration guidelines. Depending on the operational circumstances, it may be more practical to choose one type of fluid and use it throughout the dives for fluid and caloric replacement.

There are no indications that providing fat or protein will improve short-term performance. Therefore, any caloric supplementation during a dive should be in the form of carbohydrate, preferably glucose polymer solutions.

3. Postdive

Postdive diet should be the same as those recommended for the predive period. If repetitive dives will be performed, particular consideration should be given to replenishment of the body's glycogen stores. During long or strenuous work glycogen stores are significantly reduced. Inadequate carbohydrate intake (<400 gm per day) will prolong the amount of time required to restore glycogen levels.

4. Repetitive diving

Low levels of muscle glycogen will reduce performance. If hard work has been done on a dive, or if the dive was of long duration, 1-3 days of light activity should be allowed to restore glycogen levels before the next dive, while simultaneously eating a diet that provides 400-600 grams per day of carbohydrate. If the inter-dive interval must be less than 24 h, then high carbohydrate beverages should be consumed and exercise minimized during the surface interval. If a dive has been particularly arduous, and the repetitive dive interval is <24 h, full restoration of glycogen levels may not be achieved even with the high carbohydrate intake. In this instance, the subsequent dive should be planned at a less intense level of work.

F. SATURATION DIVING

Appendix E outlines the dietary recommendations for saturation diving. Some modifications to the diet may be necessary to adjust to the hyperbaric environment. For example, whipped pastries may be crushed when locked-in to the divers, milk may be

rendered unpalatable from the heat of compression and some foods may taste quite different in heliox atmospheres (17).

Evidence obtained thus far indicates that large increases in daily caloric intake are not necessary for dives in the 150-fsw range. Compared to the 24-hour free-living conditions at the surface, activity in the chamber is reduced. The 8% increase in daily caloric expenditure noted previously during working saturation dives to 150 fsw would increase the caloric requirement by only 200-300 kcal. It is possible to carefully plan balanced meals so that supplements are not necessary during saturation dives.

G. EQUIPMENT ISSUES RELATED TO IN-WATER FLUID

At present there is no convenient means to supply a diver with fluid replacement while submerged. As noted in the background section of this paper, providing fluid has equivocal effects on overall hydration status. However, the need for caloric replacement, to prevent declines in blood glucose that signal the onset of exhaustion, is indicated.

A prototype drinking tube, installed in an AGA full face mask, has been developed in the Hyperbaric Environmental Adaptation Program at NAVMEDRSCHINSTITUTE for use in research dives. A hole was drilled in the sideplate of the mask, sufficient to permit an intravenous-sized polyethylene tube to penetrate the mask through an o-ring sealed fitting. The tubing was inserted through the oronasal mask to provide access to the mouth. A plastic i.v. bag was filled with fluid and attached to the external portion of the tubing by a quick-connect plastic fitting, with a

one-way check valve to prevent water entering the mask if the tubing were disconnected. Preliminary testing revealed this system worked well during scuba dives to 15 fsw.

New generation full face masks or helmets should have drinking tubes installed. This report provides documentation that the need for in-water replenishment of fluid and calories is essential to improve mission performance. Formal operational requirements are needed to implement the engineering task to include drinking tubes in new masks or helmets. Retrofitting older masks for operational diving requires NAVSEA approval.

APPENDIX A

HYDRATION GUIDELINES

NON-SATURATION DIVES

PREDIVE	1-24 hours	sufficient fluid intake to produce clear, pale urine
	1 hour	drink 5 ml fluid per kg body weight (about 400 ml or 12 oz)
DURING DIVE	<3 hours	probably none needed optional to drink 250-500 ml/hour
	>3 hours	500 ml (16 oz) per hour containing glucose if available)
		250 ml (8 oz) about 30 min before surfacing
STANDBY DIVER		250-500 ml fluid per hour
POSTDIVE	0-6 hours	drink 1 liter fluid for each kg decrease in body weight (16 fl oz per lb)
		OR
		1 liter fluid per hour until urine is pale

APPENDIX B

HYDRATION GUIDELINES

SATURATION DIVES TO 150 FSW

Monitor fluid intake to insure that 3-6 liters of fluid are consumed per day, not including fluid normally found in food. This amount of fluid includes any beverages served with meals.

APPENDIX C

FLUID COMPARISON CHART
(Adapted from refrences (19))

BEVERAGE (8 oz or 240 ml)	CARBOHYDRATE SOURCES	% CARBOHYDRATE CONCENTRATION	OSMOLALITY (mOsm/L)	DILUTION (L water per L)
WATER	none	0	10-20	none
ORANGE JUICE	fructose, glucose sucrose	11.8	690	2:1
CRANBERRY JUICE	fructose, sucrose	15	890	3:1
COMMERCIAL BEVERAGES:				
COLA SODAS	fructose, sucrose	10.2-11.3	700	2:1
GATORADE THIRST QUENCHER	glucose, sucrose	6	360	1:1
EXCEED	glucose polymer fructose	7.2	250	none
QUICKKICK	fructose sucrose	4.7	305	1:1
10-K	sucrose, glucose, fructose	6.3	350	1:1
SQWINCHER	glucose,	6.8	470	1:1

NOTE: DILUTION of listed beverage with water is given in volume of water added to volume of beverage to reduce osmolality to <260 mOsm.

APPENDIX D

DIETARY GUIDELINES

NON-SATURATION DIVES

PREDIVE		40-50 kcal/kg/day (18-23 kcal/lb/day) 3000-4000 kcal/day 50% calories from carbohydrate (400-600 gm carbohydrate/day) 30% of calories from fat 1.0 gm protein/kg/day no vitamin supplements needed SEE APPENDIX F FOR PREDIVE MEAL
DURING DIVE	<3 hours	no calories needed optional: 7-14 gm carbohydrate solution per hour (250-500 ml/h of 7% glucose polymer solution, or equivalent from Appendix C)
	>3 hours	light work: 250 ml 7% glucose polymer solution per hour hard work: 500 ml 7% glucose polymer solution per hour
POSTDIVE		same recommendations as PREDIVE
REPETITIVE DIVES	1-3 days	avoid moderate-hard work 400-600 gm carbohydrate/day
	<24 h	600 gm carbohydrate/day; possibly in high carbohydrate beverage form. Also see Appendix G for high carbohydrate foods. Plan less strenuous dive.

APPENDIX E

DIETARY GUIDELINES

SATURATION DIVES TO 150 FSW

Follow same recommendations as PREDIVE guidelines for non-saturation dives.

See section E.1. of text and reference (17) for special consideration of food selection and preparation for use in hyperbaric environments.

Insure adequate fluid intake of 3-6 liters per day.

APPENDIX F

PREDIVE MEAL
(Developed from reference (14))

SERVING SIZE FOR 80 kg (175 lb) DIVER

<u>1-2 HOURS PREDIVE</u>: 1 gram carbohydrate/kg body weight

	SERVING	GRAMS CARBOHYDRATE
BEVERAGES ONLY	2 2/3 cups orange juice or apple juice	80
	OR	
SOLID FOOD	1 apple	21
	1 banana	27
	1 slice whole wheat bread	11
	2 tablespoons jelly	26
	TOTAL	85

<u>2-3 HOURS PREDIVE</u>: 2.5 grams carbohydrate/kg body weight

	SERVING	GRAMS CARBOHYDRATE
BEVERAGES ONLY	6.9 cups orange juice or apple juice	206
	OR	
SOLID FOOD	1 apple	21
	1 banana	27
	2 slices whole wheat bread	22
	2 tablespoons jelly	26
	1/2 cup raisins	59
	1 cup strawberry yogurt	43
	TOTAL	198

	SERVING	GRAMS CARBOHYDRATE
3-4 HOURS PREDIVE:	5 grams carbohydrate/kg body weight	
BEVERAGES ONLY	not advised unless use high carbohydrate beverages; then follow directions to drink enough to supply 400 grams	
	OR	
SOLID FOOD	1 apple	21
	1 banana	27
	4 slices whole wheat bread	44
	8 tablespoons jelly	104
	2 cups strawberry yogurt	86
	1 cup raisins	118
	TOTAL	400

NOTE: Combinations of beverage and solid food can be used by selecting appropriate amounts that add up to the desired grams of carbohydrate. Other food substitutions may be used if carbohydrate content is known and it is low in fat. Avoid more than 1-2 cups of coffee for 4 h before dive. Never drink more than 1 liter (~32 oz) of fluid in any one hour period.

APPENDIX G

HIGH CARBOHYDRATE FOODS

FOOD	PORTION SIZE	CALORIES (kcal/portion)	CARBOHYDRATE (gm/portion)
RAW APPLE	medium	81	21
APPLESAUCE	1/2 cup	96	26
BAKED POTATO	large	139	32
RAW BANANA	medium	105	27
BREAD, WHITE TOAST	1 slice	64	12
BREAD, WHOLE WHEAT	1 slice	61	11
CORN	1/2 cup	88	21
CORN BREAD	1 piece	198	29
CORN TORTILLA	6" diameter	67	13
GRAPES	1 cup	58	16
NOODLES, EGG	1 cup	178	33
PEAS, COOKED	1 cup	110	19
RAISINS	2/3 cup	300	79
RICE, COOKED	1 cup	205	45
SPAGHETTI TOMATO SAUCE	1 cup	179	34
YOGURT, STRAWBERRY	1 cup	257	43

Adapted from reference (4)

NOTE: Calories and carbohydrate content may vary slightly from these estimates because of processing, method of analysis, or exactness of portion size.

APPENDIX H

REFERENCES

1. Arnall D.A., H.W. Goforth, "Responses of cold water divers hyperhydrated with glycerol." Medicine and Science in Sports and Exercise, Vol. 22, pp. S38 (abstract), 1990.

2. Conway J.M., J.W. Thorp, T.P. Stein, J.L. Seale, W.V. Rumpler, "Decreased protein synthesis during saturation diving." American Journal of Clinical Nutrition, Vol. 51, pp. 503 (abstract), 1990.

3. Costill D.L., W.M. Sherman, W.J. Fink et al., "The role of dietary carbohydrates in muscle glycogen synthesis after strenuous running." American Journal of Clinical Nutrition, Vol. 34, pp. 1831-1836, 1981.

4. Coyle E.F., "Carbohydrates and athletic performance." Sports Science Exchange, Vol. 1, No. 7, 1988.

5. Coyle E.F., A.R. Coggan, M.K. Hemmert, J.L. Ivy, "Muscle glycogen utilization during prolonged strenuous exercise when fed carbohydrate." Journal of Applied Physiology, Vol. 61, pp. 165-172, 1986.

6. Deuster P.A., T.J. Doubt, C.J. Ryan, L.C. Montgomery, K.J. Haberman, "Fluid and cation changes during head-out immersion in 25 and 35 ° C water." Undersea Biomedical Research, Vol. 16, pp. 427-437, 1989.

7. Deuster P.A., D.J. Smith, B.L. Smoak, L.C. Montgomery, A. Singh, T.J. Doubt, "Prolonged whole-body cold water immersion: fluid and ion shifts." Journal of Applied Physiology, Vol. 66, pp. 34-41, 1989.

8. Doubt T.J., S.H. Hsieh, "Additive effects of caffeine and cold water during submaximal leg exercise." Medicine and Science in Sports and Exercise, Vol. 23, 1991 (in press).

9. Doubt T.J., K. Haberman, J.W. Thorp, R.L. Hesslink, "Glucose polymer ingestion does not alter exercise variables in 25 ° C water." Federation Proceedings, Vol. 4, pp. A1162 (abstract), 1990.

10. Doubt T.J., D.J. Smith, "Lack of diurnal effects on periodic exercise during prolonged cold water immersion." Undersea Biomedical Research, Vol. 17, pp. 149-157, 1990.

11. Doubt T.J., J.W. Thorp, "Dietary plans for carbohydrate loading." Naval Medical Research Institute Technical Report No. 89-94, 1989.

12. Doubt T.J., R.P. Weinberg, R.L. Hesslink, S.T. Ahlers, "Effects of serial wet-dry-wet cold exposure: thermal balance, physical activity, and cognitive performance." Naval Medical Research Institute Technical Report No. 89-35, 1989.

13. Seale J.L., J.M. Conway, W.V. Rumpler, J.W. Thorp, "Energy expenditure and water turnover rate during a 10 day saturation dive at 5.5 atm." Federation Proceeding. Vol. 4, pp. A854 (abstract), 1990.

14. Sherman W.M., "Pre-event nutrition." Sports Science Exchange, Vol. 1, No. 12, 1989.

15. Singh L.L., P.A. Deuster, D.J. Smith, B.A. Day, J.E. DeBolt, T.J. Doubt, "Nutritional status of land based US Navy divers." Undersea Biomedical Research, Vol. 15, pp. 135-145, 1988.

16. Stevens D.M., D. Hyde, K.J. Haberman, J.W. Thorp, T.J. Doubt, "Pyridostigmine and warm water diving protocol 90-05: V. Hydration status." Naval Medical Research Institute Technical Report No. 90-99, 1991.

17. Thorp J.W., T.J. Doubt, "Recommended meal plans for saturation diving." Naval Medical Research Institute Technical Report, 1991 (in press).

18. Thorp J.W., K.D. Mittleman, K.J. Haberman, J.F. House, T.J. Doubt, "Effectiveness of carbohydrate loading to improve work capacity in cool water." Naval Medical Research Institute Technical Report No. 90-14, 1990.

19. Coleman E., "Sports drink update." Sports Science Exchange, Vol. 1, No. 5, 1988.

FIGURE 1

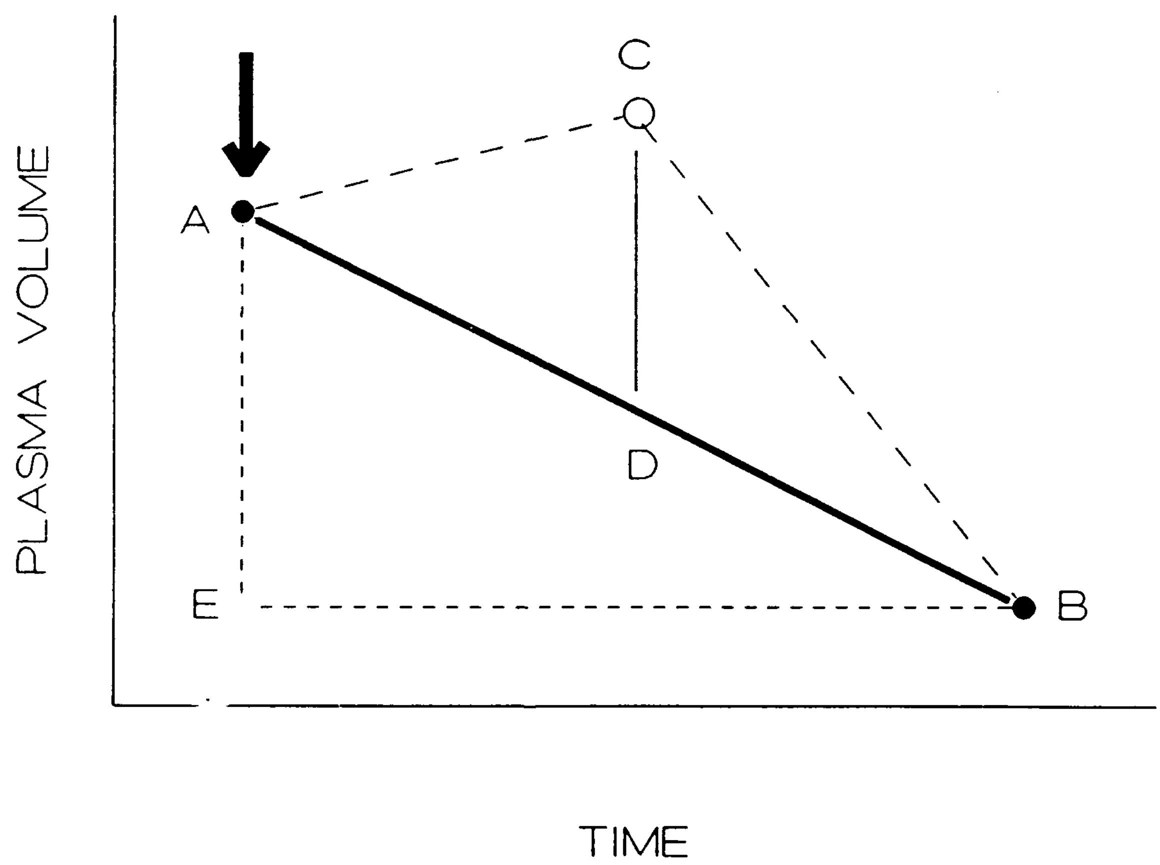


FIGURE 2

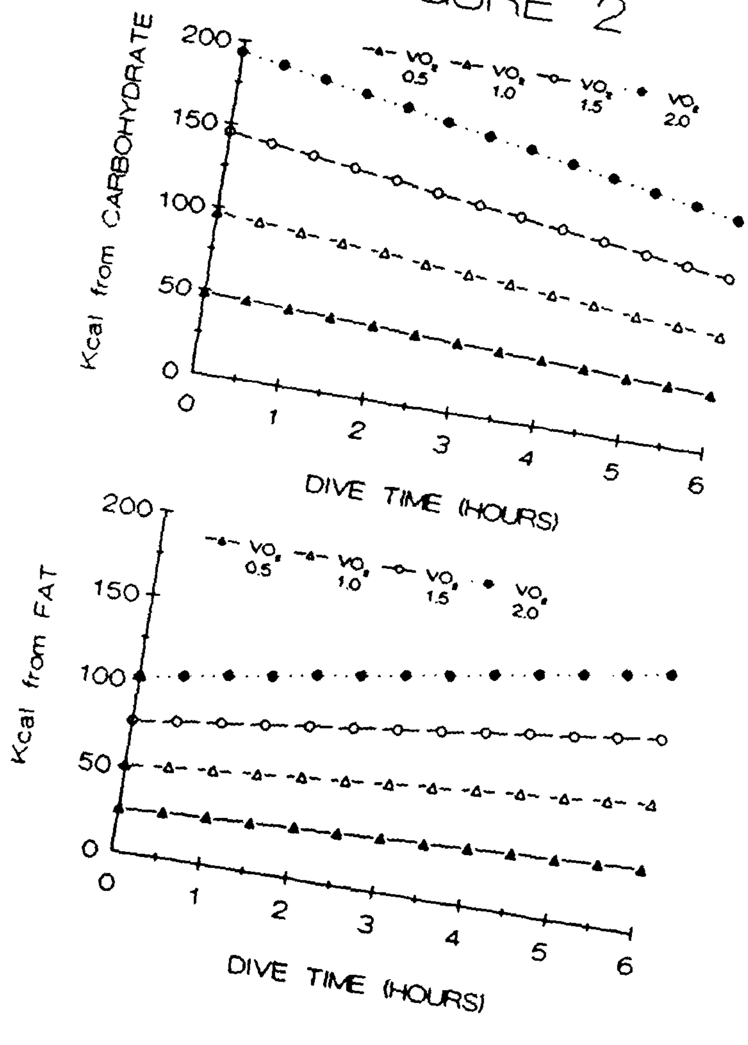
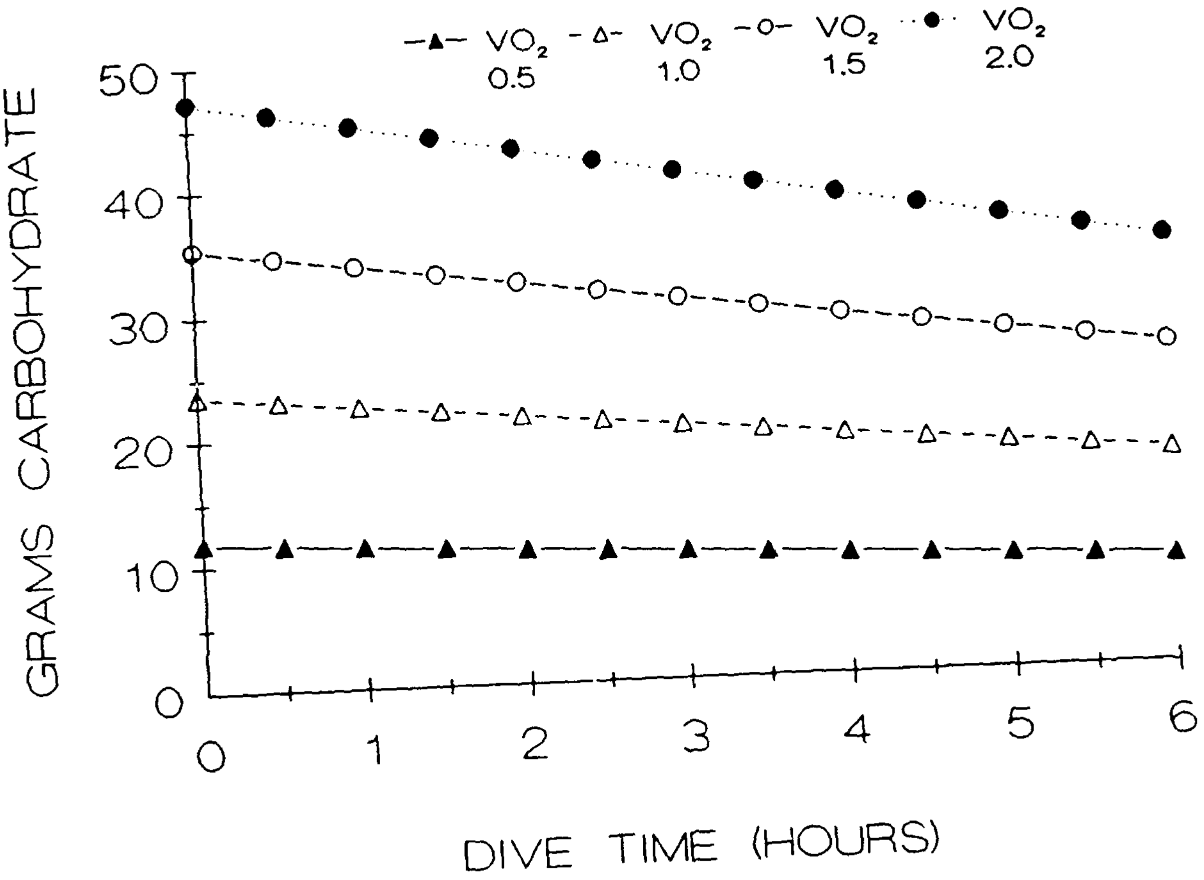

Kcal from CARBOHYDRATE
200
150
100
50
0
VO2 0.5
VO2 1.0
VO2 1.5
VO2 2.0
0
1
2
3
4
5
6
DIVE TIME (HOURS)
Kcal from FAT
200
150
100
50
0
VO2 0.5
VO2 1.0
VO2 1.5
VO2 2.0
0
1
2
3
4
5
6
DIVE TIME (HOURS)

FIGURE 3


VO2 0.5
VO2 1.0
VO2 1.5
VO2 2.0
GRAMS CARBOHYDRATE
0
10
20
30
40
50
0
1
2
3
4
5
6
DIVE TIME (HOURS)